THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

FEBRUARY 1959

Volume 53, Number 1 Whole Number 436

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

NATIONAL OFFICERS AND COUNCIL FOR 1958

Honorary President—The Honourable W. J. DUNLOP, D.PAED., Minister of Education for Ontario.
President—HELEN S. HOGG, PH.D., Toronto.
First Vice-President—ANDREW MCKELLAR, PH.D., Victoria.
Second Vice-President—PETER M. MILLMAN, PH.D., Ottawa.
National Secretary—J. E. KENNEDY, M.SC., 252 College Street, Toronto 2B.
National Treasurer—J. H. HORNING, M.A., 252 College Street, Toronto 2B.
Recorder—FREDERIC L. TROYER, Toronto.
Librarian—W. T. TUTTE, PH.D., Toronto.
Council—Elective Members: MIRIAM S. BURLAND, Ottawa; A. VIBERT DOUGLAS, Kingston; CARL REINHARDT, Toronto; Past Presidents: R. M. PETRIE, Victoria; JOHN F. HEARD, Toronto.

Halifax Centre: Rev. M. W. BURKE-GAFFNEY, S.J., L. CARRIGAN (Pres.).
Quebec Centre: PAUL H. NADEAU, J. ALFRED DUMONT (Pres.).
Montreal Centre: A. R. MACLENNAN (Pres.).
Centre Français de Montréal: J. R. GRIGNON, JEAN ASSELIN (Pres.).
Ottawa Centre: J. L. LOCKE, J. E. LILLEY (Pres.).
Toronto Centre: MRS. K. M. HEATON, G. A. COOPER (Pres.).
Hamilton Centre: H. B. FOX, REV. N. GREEN (Pres.).
London Centre: W. G. GRAHAM, W. WEHLAU (Pres.).
Windsor Centre: ————————, E. W. KEITH (Pres.).
Winnipeg Centre: R. J. LOCKHART, J. SCATLIFFE (Pres.).
Edmonton Centre: E. S. KEEPING, EARL MILTON (Pres.).
Calgary Centre: ————————, WALTER H. STILWELL (Pres.).
Vancouver Centre: G. M. SHRUM, R. J. CLARKE (Pres.).
Victoria Centre: R. S. EVANS, N. G. ROGERS (Pres.).

PRINTED IN CANADA
BY THE UNIVERSITY OF TORONTO PRESS

THE JOURNAL OF THE
ROYAL ASTRONOMICAL SOCIETY
OF CANADA

Vol. 53, No. 1 FEBRUARY 1959 Whole No. 436

VARIABLE STAR OBSERVING IN NEW ZEALAND—II

By Frank M. Bateson
Astronomical Society of New Zealand

Amateur Variable Star Organisations. Before discussing the future plans of the New Zealand Variable Star Section in particular, it is an advantage to consider such Sections in general. Briefly, amateur variable star organisations exist in order to channel the interests of observers, who wish to do useful work, into a field particularly suited to the amateur. It is the duty of these organisations to provide their members with the necessary guidance, charts and sequences. They also direct the observers as to which variables are to be observed.

Up to this point all organisations have common aims. They differ from one another in their methods of handling the observations. Some collect the records of their members and then send these to some other larger organisation, such as the A.A.V.S.O. Others ask their members to send the results direct to the larger organisation and are not themselves concerned in handling the observations in any way. Several, however, publish the observations. A small minority not only publish the records but also use these to deduce light curves and other data. In general such bodies extract the maximum possible information from the observations. These data they make available, in various forms, to the professional astronomers.

In the past each national organisation has, in general, provided its members with instructions independent of what other national societies are doing. These societies are necessary since they provide better direction and more personal encouragement than a larger, and usually more distant, central bureau. The nearest organisation to an international body is the A.A.V.S.O. Whilst it has members in many countries there are regions into which its activities do not extend.

The study of variable stars is a vast and complex one. It is of the greatest importance in understanding the nature of the stars as a whole. Before the theoretical astronomer can explain *why* some stars vary he must know *how* they vary. With the vast number of variables it is impossible for any observatory or group of observatories to follow any except a few, unless they dropped all other programmes. This is why there is such an unlimited field for the serious amateur to provide the records that will tell how the stars vary.

The day has come, however, when the amateur organisations should think and plan together on an international scale. It should no longer be a case of each society proceeding on its own. The programmes of all the national organisations should interlock, so that the greatest possible number of variables are adequately observed and unnecessary duplication avoided. Charts and sequences should be standardised.

That the views expressed are justified appears to be supported by the resolutions passed at the I.A.U. Dublin Meeting (I.A.U., 1956). At the same meeting it was made quite clear that there is, and will be for a long time, essential visual work for the amateur. The informal discussions at Dublin (*Sky and Telescope*, 1956) stressed the same viewpoint.

Aims of the New Zealand Section. It is not much use making comments like the foregoing, unless one is prepared to do something about the problem. The writer recently made a tour of many Canadian and American Observatories, the purpose of which was simply to learn in what way the New Zealand Variable Star Section could improve its work. Labouring far from any centre of astronomical research, one could easily have warped notions that needed correction.

It was possible, during an extended stay at Cambridge, Mass., to discuss closer co-ordination of the programmes of the N.Z. Section and the A.A.V.S.O. with the Director of the latter organisation, Mrs. Margaret Mayall. Proposals to this end were formed and were submitted to Commission 27, I.A.U. at the Moscow meeting. It was agreed that the N.Z. Section should be freed from following any long-period variables north of declination $-20°$, so that they could include more of the southern stars in their programme. It was recognised, however, that due to its filling a vital longitude gap, the N.Z. Section would continue to observe the peculiar variables, such as U Gem type and others, that require to be followed continuously.

The standardisation of charts was agreed on by the two Directors. It was arranged that the N.Z. Section keep the A.A.V.S.O. informed of revisions to southern charts and sequences. Many other matters were

discussed. It is hoped that the result will be a very close co-ordination of the two programmes. This fulfills a recommendation of Commission 27 (I.A.U., 1956).

Against the preceding remarks, and also benefiting from the knowledge acquired during his trip to North America, the writer feels that the future aims of the N.Z. Section can be summarised as:

(1) To observe adequately as many southern variables, suited to visual methods as possible.
(2) To continue to publish the observations regularly and promptly in the same form as in the past.
(3) The publication of research papers, dealing with individual stars, to be maintained and increased as possible. Memoirs, covering a decade or more, to be issued, but, in a somewhat improved form compared to that of the first *Bulletin* (Bateson, 1944).
(4) Predictions and predicted light curves to be available to those requiring them.
(5) Every effort to be made to obtain reliable charts and sequences for southern variables.
(6) Programmes to be co-ordinated with the A.A.V.S.O. and other organisations.

These points give more definite direction to the general past programme. They also point up the truth of the contention that if an organisation goes far enough, it ultimately faces the problem that its expansion must stop or that it must become a full time professional organisation, as far as its Headquarters are concerned.

This fact has been clear to the writer for many years, and he has tried to build accordingly. The limiting factor has been finance. It has been necessary to provide funds for housing, a library and some instruments together with something to carry the Headquarters through its initial years on a full time basis. With these requirements nearing fulfillment it is planned to establish a permanent full time Headquarters for the Section in the southern summer of 1960–61. These headquarters will be within New Zealand proper and it is believed that these plans will improve the contribution that the New Zealand Section can make.

This is especially so with the growth of observatories, both actual and planned, throughout the southern hemisphere. Possibly it is a radical thought, but it is believed that ultimately there should be some central, international variable star organisation in the southern hemisphere. If the work that has to be done is performed properly then there appears to be a need for such an organisation dealing with the southern variables. These are only personal views. Before they can be translated into reality there are other national organisations that have to be consulted. Better ideas may well be produced.

Against this background of definite aims and plans, it is now possible to detail some of the steps taken, and projected, to overcome the problem of charts and sequences discussed in the first article.

Charts and Sequences. Through the courtesy of the Director of the Cape Observatory, it has been possible to submit to his Observatory some of the A.A.V.S.O. southern charts and sequences for revision and additions. As a first step we have supplied tracings of these charts, on which additional comparison stars have been marked. The Cape Observatory has very kindly undertaken to determine the magnitudes of these stars on the SPv system, as their programmes permit. For some other variables they have already sent us photographic charts, from which we have selected suitable comparison stars. For these Jones and Bateson determined preliminary. magnitudes. Naturally these are subject to correction at the Cape in due course. But this procedure saves them valuable time. The limiting factor as far as the Cape is concerned is available telescope time and manpower in conjunction with the heavy programmes they have to carry out.

These form a most useful start. As the Cape photometric programmes progress it will be possible for us to produce many more preliminary sequences, using stars for which magnitudes have been determined as the zero points. Some time ago the Cape offered the useful suggestion that the determination of final sequences could be accelerated if we had photoelectric equipment at our disposal. When the writer's 16-inch reflector arrives it should be possible to use this instrument with a photoelectric photometer.

There are many variables, especially of the semi-regular types, north of $-30°$ observable from the southern hemisphere. Quite a number of these are neglected and no charts or sequences are available. The defect of lack of charts is being remedied through the kindness of the Directors of the Yerkes and Lick Observatories. As a result of my visits they have kindly supplied charts that will fill this gap.

It has also been arranged with the Lembang Observatory that they will determine visual magnitudes for a limited number of variables previously investigated there photographically.

Through the kind co-operation of the Director of the Harvard College Observatory it was possible to use their plate collection from which to select plates that will be useful for charts, either detailed or finder. At the same time, during my stay at Cambridge, Dr. Sergei Gaposchkin made available his card records of Milton Bureau variables.

During my tour of North America it was possible to study many

papers not available in N.Z. and from some of these earlier charts have been tracked down. From all these sources, and others, it is hoped first to produce charts for several hundred variables. That will be a preliminary to the establishment of sequences. The speed at which this latter work can be done will depend upon what photoelectric photometer the writer can secure.

Meantime, of course, many variables are under observation with preliminary sequences. And as the charts become available to our members the list of such variables will be extended. In time it is hoped to observe adequately all the long period variables south of declination −30°, brighter than magnitude 10 (visual) at maxima. For other classes, such as U Gem, R CrB, Recurrent novae, etc. it is planned to follow such stars brighter than twelfth or possibly thirteenth magnitude.

Paralleling such expansion are plans for training observers and increasing their astronomical horizons in accordance with the I.A.U. resolution (I.A.U., 1956). The writer has prepared a booklet for this purpose. So that it can have a much wider circulaton than would be provided by membership of the Royal Astronomical Society of N.Z. it is being published privately and distributed free throughout the southern hemisphere.

Publications. The question of publications in the future was one on which expect opinions were sought. The quarterly *Circulars* containing observations will continue as at present. Also, as has been done in recent years, these will be supplemented by additional *Circulars* dealing with particular variables. Such *Circulars* contain charts, sequences, light curves and other relevant data.

With the *Memoirs*, the second of which is due, it has been urged upon me that these be expanded. Naturally an ideal model at which to aim is along the lines of the Leon Campbell Memorial volume (A.A.V.S.O., 1955). At present we cannot fully emulate this admirable volume, but there is sufficient material available to improve considerably the material presented in the first *Memoir*. Publication will be delayed for a few years, but it will be possible to incorporate work of twenty years that has been done since the publication of the first *Memoir* (Bateson, 1944).

It is also our policy to encourage members of the Society who prefer desk work, to prepare papers and investigate particular stars. In the past such people have been slow in coming forward, but there are signs that much more interest is now being taken in this phase of our activities.

Acknowledgements. The writer has to thank the Director of the Cape Observatory for the invaluable assistance and encouragement of his staff.

Especially in providing charts and magnitudes whenever possible. He is also under a great debt of gratitude to the Directors and staffs at all the Canadian and American Observatories he has so recently visited; they made their facilities freely available, and gave most kindly encouragement, advice and help to the projects discussed in these articles.

It is invidious to mention individual names when so many people have been so kind. I hope that all will understand if I mention one name. I would like to record the magnificent contribution that has been made to our Section's work by Albert Jones of Timaru. The skill and accuracy of his observations are matched only by their persistency and numbers.

References

A.A.V.S.O. 1955. "Studies of Long Period Variables" by Leon Campbell & edited by Margaret Walton Mayall.

Bateson, F. M. 1944. *Bulletin* V.S.S., R.A.S.N.Z., no. 1.

I.A.U. 1956. *Transactions I.A.U.*, vol. IX, pp. 368–385.

Sky and Telescope. 1956. vol. XV, no. 3. pp. 119–120.

THE CHARACTERISTICS OF SUBDWARF STARS

By William Buscombe
Mount Stromlo Observatory, Canberra, Australia
Received 1958 August 15

Spectra. Early in the course of his work on the luminosity classification of stellar spectra, Adams (1915) announced the discovery of three faint A-type stars with abnormally weak lines of Mg II λ4481 and Fe II λ4233. Two of the three stars have large proper motions. Within a few years three similar stars were discovered, and as trigonometric measures of their parallaxes became available, Adams and his associates (1935) showed that the "intermediate white dwarfs" form a group with absolute magnitudes close to +5. Although bluer and hotter, they have no greater intrinsic luminosity than the sun, and fall about two magnitudes below and to the left of the main sequence for normal dwarfs on the H-R diagram. Five more A-type subdwarfs have been added to the list from Palomar spectrograms by Greenstein (1954).

At Yerkes Observatory, Kuiper (1938, 1939) made a spectral survey of stars having proper motions exceeding 0."30 per year. He found, from trigonometric parallaxes, that some stars of this group fall 2 to 3 magnitudes below the main sequence along almost its entire length. As stars of this class are more similar to those of the main sequence than to the much fainter white dwarfs, he suggested the name "subdwarfs", by which these stars are now known. After both Kuiper and Adams had described the distinguishing spectral characteristics in very similar terms, it was surprising that Morgan and his co-workers did not set them apart to form a Luminosity Class VI in the revised Yerkes system of classification, although in the original *Atlas of Stellar Spectra* they had shown the spectral peculiarities of certain high-velocity stars. However, as only a few subdwarfs are brighter than the eighth magnitude, not enough spectra could be photographed at the 40-inch refractor with dispersions of the range 75 to 125 A./mm.

When the 82-inch telescope in Texas was brought into use, spectra were taken of a considerable number of stars with large transverse motions and reliable trigonometric parallaxes. In this survey 200 stars were found to have the spectral features of subdwarfs. The majority of these were photographed by Kuiper (1940) with a dispersion of 340 A./mm., and later

the work was continued by Popper (1942, 1943) and Münch (1944), using 76 A./mm. From spectra secured with the Perkins reflector, Keenan and Keller (1953) have discussed the classification of the brighter northern stars of high velocity. Although the term "subdwarf" is not mentioned, the points for the two stars H.D. 103095 and 140283 fall conspicuously below the main sequence in their spectrum-luminosity diagram. In her *Catalogue of High-Velocity Stars*, Miss Roman (1955) has designated the subdwarfs of spectral type later than G0, which she has classified at Yerkes and McDonald Observatories, as luminosity class VI. She has described in special detail a group of 17 stars of type F, which show extreme subdwarf special characteristics, abnormally negative *U-B* colours for a given *B-V* value, and highly eccentric orbits around the galactic centre (Roman, 1954). Those south of the equator are included in the finding list of *Southern Stars of High Velocity*, which has recently been compiled by Buscombe and Miss Morris (1958). Spectroscopic observations are being made at Mount Stromlo of fifty stars from this list which show some subdwarf characteristics. SX Phoenicis, the RR Lyrae-type variable with the shortest known period, has a spectrum resembling a subdwarf star, varying from type A2 to about A7 (Kuiper, 1940; Joy, 1947).

For convenience of reference, the spectroscopic features which distinguish subdwarfs from ordinary dwarfs are quoted from a detailed discussion by Joy (1947) and other sources. In subdwarfs of all spectral classes there is a general weakening of the absorption spectrum. Among stars of early type the Balmer lines of hydrogen are abnormally narrow and sharp, and Mg II λ 4481 as well as Fe II λ 4233, weak or barely visible. In F and G stars the *G* band of the CH molecule blended with atomic lines is rather weak, but in the later types the CN band at λ 4215 is strengthened, and emission lines are weaker. A short time ago Miss Tomasik (1956) reformulated the criteria of differences in line strengths by which the spectra of faint F, G and K stars of Populations I and II may be distinguished with low dispersion. Oke (1957) has recently pointed out that some ratios of measured intensities of spectral lines, which are most sensitive to luminosity differences, exhibit a regular sequence from giant stars across the main sequence to subdwarf stars of the same spectral subclass among types F and G. A detailed study from spectrograms with high dispersion has only appeared for stars of types A and F, but further studies of subdwarf spectra are in progress at Mount Wilson and Palomar. Chamberlain and Aller (1951) found the atmosphere of H.D. 19445 and 140283 deficient in calcium and iron relative to hydrogen, but regard their spectra as closer to type F. A similar departure from normal relative

abundances was observed in three F dwarfs of high velocity by Schwarzschild and Schwarzschild (1950). Slettebak (1952) has published a very clear reproduction of a spectrogram of the A-type subdwarf H.D. 161817, while the spectrum of H.D. 19445 is shown in a review article by Mrs. Burbidge and others (1957). These authors quote an unpublished suggestion by Greenstein and Aller that this star has a temperature similar to the sun's, and may not be a subdwarf at all. This opinion is based on measures of line strengths on Palomar spectrograms. This interpretation would, however, contradict the assignment made by Adams and his associates (1935), as well as a great deal of the later work reviewed in this article. Babcock (1958) reports that H.D. 19445 has a magnetic field of moderate strength. In an earlier paper Burbidge and Burbidge (1956) have shown from curves of growth for several A and F stars, that their atmospheres are also relatively deficient in the heavier elements, but not to the same extent as H.D. 19445 and 140283. This evidence of a continuous variation of relative abundances between the atmospheres of stars representing the extremes of Populations I and II is strengthened by the results obtained by Schwarzschild and others (1957) from spectrophotometry of two groups of K giants with high and low velocities, and also by the cyanogen deficiency in G giants with high velocities, observed by Greenstein and Keenan (1958). Johnson and Morgan have found a significant scatter in the colour-differences of nearby F stars, which Strömgren (1957) now finds is due to a variable ratio of heavy elements to hydrogen, reaching a minimum in Population II subdwarfs.

Kinematics. From a discussion of the space motions of subdwarf stars, Lohmann (1948) concluded that the majority of subdwarfs have galactocentric orbits of high eccentricity, and pass close to the centre of the spherical galactic halo, but are distributed in a wide range of inclinations to the plane of the spiral arms. In a carefully documented review of the original observational data, he obtained mean absolute magnitudes for subdwarfs of the various spectral classes. The motions of the sun relative to the average of 79 well-observed subdwarfs was found by Fricke (1949, 1950) very similar on the average to that relative to the RR Lyrae variables and globular clusters, but also with a very large dispersion. Similar conclusions were reached independently by Parenago (1946, 1949, 1951) in the course of an extensive analysis of the motions of groups of stars with very different characteristics, which led him to describe the subdwarfs as members of the most nearly spherical of the various distributions with respect to the galactic plane of symmetry. Dziewulski (1951, 1953) concluded that about 39 per cent. of the subdwarfs have high velocities

relative to the sun, but since he has applied small increments to the small positive and even negative trigonometrical measures in deriving the transverse velocity components, one can have little confidence in the result of any statistical discussion which includes stars more than 100 parsecs from the sun.

Photometry. In recent years, the most definite evidence that subdwarfs form a distinct class of stars has come from photoelectric photometry. In a study of the nearest moving cluster to the sun, Eggen (1950) drew attention to three stars of the Hyades which fall below and to the left of the main sequence in the colour-luminosity array. In other words, they are bluer than other stars of the same luminosity, or less luminous than main sequence stars with the same colour. On the other hand, Greenstein (1958) has stated that these stars seem to have essentially normal spectra, completely different from the high-velocity subdwarfs. While each of these three stars had been considered by both Wilson (1948) and van Bueren (1952), from measurements of proper motions and radial velocity, as a certain member of the Hyades cluster, H.D. 27685, the only one of them included in the region studied by Osvalds (1954), is described by him as a doubtful member, and later by Heckmann and Lübeck (1956) as an improbable member. On their colour-luminosity diagram, this star falls only slightly below the main sequence for the cluster, almost in the same position as star H.D. 26756, another of the stars considered as subdwarfs by Eggen. His third star, B.D. $+19^\circ$ 641, has not been measured in the Hamburg photometric study. On the other hand, all three of Eggen's "subdwarfs" fall on the main sequence plotted by Johnson and Knuckles (1955) on the basis of photoelectric photometry on the *U*, *B*, *V* system. However, these authors have found that 17 other outlying stars of which the majority are, according to van Bueren and Osvalds, certain members of the Hyades, fall below and to the left of the main sequence, and show the same sort of ultraviolet excess which has been measured for known subdwarfs. Two of the same stars, B.D. $+13^\circ$ 671 and $+14^\circ$ 685, and three others, among which are some doubtful members, are shown to diverge in the same way from the main sequence by the photographic photometry of Heckmann and Lübeck. The cause of the different assignments lies in the slightly different statistical analyses of the observed proper motions.

The photoelectric colour-luminosity curve given by Johnson (1952) for stars considered members of the open cluster Praesepe by Klein-Wassink (1927) and confirmed by Haffner and Heckmann (1937, 1940) on the basis of photographic photometry and improved measures for the proper motions, shows five stars below the main sequence which are probably

faint subdwarfs. It would not be in accord with current ideas on cosmology to include high-velocity stars of Population II as members of a galactic open star-cluster. However, the assignment of a few faint subdwarfs, having motions parallel to the cluster, to membership may be consistent with the previous statement that more than half of the known subdwarfs have low velocities relative to the sun. For the Praesepe cluster and the Hyades, the assignment of many faint stars to membership will remain uncertain until radial-velocity measures become available. From his photoelectric colour-magnitude array for the Ursa Major Stream, using stream parallaxes, Miczaika (1954a, b) has delineated a subdwarf sequence of a dozen stars 1.2 magnitudes below the main sequence. These also appear to have normal dwarf spectra. He has expressed the opinion (1954a) that subdwarfs occur only in those clusters (Hyades, Praesepe, Ursa Major) which also contain giant stars, but not in the young clusters (Pleiades, N.G.C. 2362) containing B-type stars.

Among stars within 20 parsecs of the sun, for which very accurate trigonometric parallaxes are available, Eggen (1950, 1955, 1956) observed a sequence of subdwarfs with spectral types later than the sun's, below the main sequence of the colour-luminosity array from photoelectric measures through blue and yellow filters. On the basis of these observations, Parenago (1954) has suggested a list of normal colour indices for subdwarfs of various spectral types. Johnson and Morgan (1953) also discussed some of the same stars on the basis of photoelectric photometry on the *U*, *B*, *V* system. In the same article they concluded that the suspected subdwarfs in the region of Praesepe are really background stars of the main sequence, and not members of the cluster at all. Kron and others (1957) distinguished several M-type subdwarfs by similar departures from the red-infrared colour arrays for the nearest stars, of which about three per cent. are abnormally strong in the infrared for their *P*-*V* colours, including some with low as well as high velocities relative to the sun. The existence of a subdwarf sequence among stars near the sun has been confirmed by Yates (1954) and also by Nikonov and others (1957) from photoelectric observations. Miss Roman (1954) has suggested that the excess luminosity in shorter wave-lengths is due to the general weakness of the metallic lines in the spectrum, and consequently is a sensitive indicator of the lower abundance of metals relative to hydrogen. From preliminary measures by Schwarzschild and others (1955) of the blanketing effect in the violet part of the spectrum, this seems quite probable. Mrs. Burbidge is at present examining the question in more detail. Miss Roman (1956) has recently shown that the ultraviolet excess is especially frequent among subdwarfs with high velocities relative to the sun.

From photometric studies of the continuous spectrum, Mlle. Divan (1956) has shown that the weakness of the Balmer absorption continuum could account completely for the difference in colour gradient from normal dwarfs. On the other hand, because the metallic lines are weak, the higher members of the Balmer series are individually well resolved in the spectra. Mlle. Divan (1957) has further studied the spectra of the two brightest suspected subdwarfs from Johnson and Knuckles' (1955) colour-magnitude array in the Hyades, but concluded that, as their Balmer continua appear similar to normal F dwarfs, they also must be background stars beyond the cluster.

The scarcity of binary systems among the stars of high velocity has already been noted (Buscombe and Morris, 1958). Eggen (1950, 1955, 1956 a, b) has included among his photometric studies the subdwarf components of seven visual binary systems. In addition to these stars, Parenago and Mme. Massevich (1951) have discussed thirteen eclipsing systems, mainly very close pairs, from which they drew the general conclusion that subdwarfs are undermassive even for their low luminosity. (Unfortunately the reasoning behind the assignment of these latter stars to the subdwarf class is not published, and in fact some are again described as *subgiants* by Kopal and Mrs. Shapley (1956)). However, a similar conclusion was expressed rather more tentatively by Eggen (1956 a). Reddish (1955) has indicated very generally the sort of parameters for physical conditions from which models for appropriate masses might be computed. A model constructed by Reiz (1954) on the assumption of negligible heavy-element content, with energy production from the proton-proton reaction, led to a star with luminosity below the main sequence for the same effective temperature.

Current Studies. In the course of this article, the principal types of information used to discover subdwarfs have been reviewed in nearly chronological order of their use. First the spectral peculiarities were noted. The correlations with large proper motions, and later with large radial-velocity components, were used to search for more stars with similar spectra. Then the abnormal colours were measured by photoelectric techniques. Eventually the historical sequence was reversed in Humason and Zwicky's (1947) search for faint blue stars in the regions of the Hyades cluster and the north galactic pole. Greenstein (1956) has studied the spectra of these stars, some of which are white dwarfs, while he found that others represent a distinctly new type of hot subdwarfs of classes O and B, which show abnormally strong and very broad helium lines but weak hydrogen, since that element has been

nearly exhausted even in the atmosphere through the evolution of energy production. Greenstein and Münch are now studying seven of these stars from Palomar coudé spectrograms. Among these Münch (1958) has analysed H-Z 44, in whose atmosphere helium is more abundant than hydrogen, and nitrogen much more than carbon. The Burbidge group (1957) has suggested that this may indicate a second stage of stability in the evolution of the stars, when the principal source of energy is from helium-burning in the central core. Greenstein is also attempting to classify about 80 subdwarfs in a consistent sequence from spectra of the highest dispersion available anywhere. Another detailed study is in progress at the David Dunlap Observatory, where Searle is examining the spectral peculiarities of high-velocity and subdwarf stars on plates of moderate dispersion.

Summary. This review has been undertaken in connection with planning for spectroscopic observation of southern stars of high velocity, to collect many fragments of information about subdwarf stars which have become scattered through the literature. From the observed spectra and motions of over 200 of these objects, we know reasonably well how they form a separate sequence on the Hertzsprung-Russell diagram, and that an unusually high proportion of them are at high galactic latitudes, moving with large Z-velocity components in galactocentric orbits of high eccentricity. A few accurate colour measurements show that subdwarfs are relatively stronger than normal dwarfs in the ultraviolet region of the spectrum. Their masses may be somewhat below the usual mass-luminosity relation.

I am grateful to Drs. Divan, Gascoigne and Greenstein, who have made a number of suggestions after reading the manuscript.

References

Adams, W. S. 1915, *Ap. J.*, vol. 42, p. 187.
Adams, W. S.; Joy, A. H.; Humason, M. L. and Brayton, Ada M. 1935, *Ap. J.*, vol. 81, p. 191.
Babcock, H. W. 1958, *Ap. J. Supp.*, vol. 3, p. 141.
Bueren, G. van. 1952, *B.A.N.*, vol. 11, p. 385.
Burbidge, E. Margaret, Burbidge, G. R., Fowler, W. A. and Hoyle, F. 1957, *Rev. Mod. Phys.*, vol. 29, p. 547.
Burbidge, G. R. and Burbidge, E. Margaret. 1956, *Ap. J.*, vol. 124, p. 116.
Buscombe, W. and Morris, Pamela M. 1958, *Mem. Mt. Stromlo Obs.*, no. 14.
Chamberlain, J. W. and Aller, L. H. 1951, *Ap. J.*, vol. 114, p. 52.
Divan, Lucienne. 1956, *Ann. d'Ap.*, vol. 19, p. 287; 1957, *C.R.*, vol. 245, p. 404.
Dziewulski, W. 1951, *Bull. Torun Astr. Obs.*, no. 10; 1953, Ibid., no. 12.

Eggen, O. J. 1950a, *Ap. J.*, vol. 111, p. 65; 1950b, *Ap. J.*, vol. 112, p. 141; 1955, *A.J.*, vol. 60, p. 401; 1956a, *Proc. Third Berkeley Symposium on Mathematical Statistics and Probability*, ed. J. Neyman, University of California Press, vol. 3, p. 1; 1956b, *A.J.*, vol. 61, pp. 361 and 405.

Fricke, W. 1949, *A.N.*, vol. 277, p. 241; 1950, Ibid., vol. 278, p. 121.

Greenstein, J. L. 1954, *P.A.S.P.*, vol. 66, p. 126; 1956, *Proc. Third Berkeley Symposium on Mathematical Statistics and Probability*, ed. J. Neyman, University of California Press, vol. 3, p. 11; 1958, private communication.

Greenstein, J. L. and Keenan, P. C. 1958, *Ap. J.*, vol. 127, p. 172.

Haffner, H. and Heckmann, O. 1937, *Veröff. Göttinger Stw.*, Nr. 55; 1940, Ibid., Nr. 66 and 67.

Heckmann, O. 1956, *Zs. f. Ap.*, vol. 40, p. 1.

Humason, M. L. and Zwicky, F. 1947, *Ap. J.*, vol. 105, p. 85.

Johnson, H. L. 1952, *Ap. J.*, vol. 116, p. 640.

Johnson, H. L. and Knuckles, C. F. 1955, *Ap. J.*, vol. 122, p. 209.

Johnson, H. L. and Morgan, W. W. 1953, *Ap. J.*, vol. 117, p. 313.

Joy, A. H. 1947, *Ap. J.*, vol. 105, p. 96.

Keenan, P. C. and Keller, G. 1953, *Ap. J.*, vol. 117, p. 241.

Klein Wassink, W. J. 1927, *Pub. Kapteyn Astr. Lab. Groningen*, no. 41.

Kopal, Z. and Shapley, Martha B. 1956, *Jodrell Bank Annals*, vol. 1, p. 141.

Kron, G. E.; Gascoigne, S. C. B. and White, H. S. 1957, *A.J.*, vol. 62, p. 205.

Kuiper, G. P. 1938, *Ap. J.*, vol. 87, pp. 78 and 594; 1939, *Ap. J.*, vol. 89, p. 548; 1940a, *Ap. J.*, vol. 91, p. 269; 1940b, *Ap. J.*, vol. 92, p. 126.

Lohmann, W. 1948, *Zs. f. Ap.*, vol. 25, p. 293.

Miczaika, G. R. 1954a, *Mem. Soc. Roy. Sci. Liège*, vol. 14, p. 275; 1954b, *A.J.*, vol. 59, p. 233.

Münch, G. 1944, *Ap. J.*, vol. 99, p. 271; 1958, *Ap. J.*, vol. 127, p. 642.

Nikonov, V. B.; Nekrasova, S. V.; Polosuhina, N. S.; Rachkovsky, D. N. and Chuvajev, K. K. 1957, *Comm. Crimean Ap. Obs.*, vol. 17, p. 42.

Oke, J. B. 1957, *Ap. J.*, vol. 126, p. 509.

Osvalds, V. V. 1954, *A.N.*, vol. 281, p. 193.

Parenago, P. P. 1946, *A.J. U.S.S.R.*, vol. 23, p. 31; 1949, *Contr. Sternberg Astr. Inst.*, no. 30; 1951, *Publ. Sternberg Astr. Inst.*, vol. 20, p. 26; 1954, *Voprosi Kosmogonii*, vol. 2, p. 261.

Parenago, P. P. and Massevitch, Alla G. 1951, *Pub. Sternberg Astr. Inst.*, vol. 20, p. 81.

Popper, D. M. 1942, *Ap. J.*, vol. 95, p. 307; 1943, *Ap. J.*, vol. 98, p. 209.

Reddish, V. C. 1955, *M.N.*, vol. 115, p. 32.

Reiz, A. 1954, *Ap. J.*, vol. 120, p. 342.

Roman, Nancy G. 1954, *A.J.*, vol. 59, p. 307; 1955, *Ap. J. Supp.*, vol. 2, p. 195; 1956, *A.J.*, vol. 62, p. 146.

Schwarzschild, M. and Schwarzschild, Barbara. 1950, *Ap. J.*, vol. 112, p. 248.

Schwarzschild, M.; Schwarzschild, Barbara; Searle, L. and Meltzer, A. 1957, *Ap. J.*, vol. 125, p. 123.

Schwarzschild, M.; Searle, L. and Howard, R. 1955, *Ap. J.*, vol. 122, p. 353.

Slettebak, A. 1952, *Ap. J.*, vol. 115, p. 576.

Strömgren, B. 1957, *A.J.*, vol. 62, p. 319.

Tomasik, Halina. 1956, *Bull. Torun Astr. Obs.*, no. 13, p. 24.

Wilson, R. E. 1948, *Ap. J.*, vol. 107, p. 119.

Yates, G. G. 1954, *M.N.*, vol. 114, p. 213.

THE MEANOOK-NEWBROOK METEOR OBSERVATORIES*

By Peter M. Millman
National Research Council, Ottawa

Introduction. The establishment of two meteor observatories, located in Alberta some 60 to 70 miles north of Edmonton, was a direct result of informal discussions held in Cambridge, Massachusetts, during March of 1946. These conversations dealt with the future of photographic meteor research and those participating included Professor F. L. Whipple of the Harvard Observatory, Dr. Zdenek Kopal from M.I.T., Commander W. E. Bleick and Dr. R. J. Seeger, representing the U.S. Navy, and the writer, at that time in the Division of Research and Development of the R.C.A.F.

Note was taken of the value in upper atmosphere research of photographic meteor heights and velocities, as demonstrated by Whipple (1943), and of the studies of meteor spectra by Millman (1932, 1935). It was felt that, in view of the fast growing interest in the upper atmosphere after the termination of World War II, meteor research by photography should be expanded through the development of improved instruments and the institution of systematic observing programmes.

Tentative agreement was reached on a general basis for co-operation in this work between the United States and Canada. Meteor observation stations, established in the two countries, would make possible a large latitude spread in a study of the properties of the upper atmosphere; the Harvard Observatory, supported by the U.S. Navy, would take the major responsibility for the development of new meteor cameras; the reduction of direct meteor photographs for heights and velocities would be carried out at M.I.T.; and the headquarters for the reduction of meteor spectra would be in Ottawa.

In May 1946, an official letter from Vice Admiral G. F. Hussey, Jr., Chief of the Bureau of Ordnance, U.S. Navy, invited Canadian participation in a project for the study of the upper atmosphere through meteor photography. This project was being conducted in the United States by the Harvard Observatory under contract from the Bureau of Ordnance. After consultation with Mr. R. Meldrum Stewart, the Dominion Astronomer, it was agreed that the Dominion Observatory in Ottawa would conduct the Canadian share of this research programme, and in July 1946, the writer joined the staff of the Dominion Observatory to plan the development of meteor research there.

**Contributions from the Dominion Observatory*, Vol. 2, No. 29.

Location of Canadian Stations. To give the required latitude spread, it was desirable to locate the Canadian meteor stations as far north as practicable. It was not advisable to place them so far north, however, that daylight would prevent observations over too long a period near the summer solstice. The zone of maximum auroral frequency of occurrence lies further north in the west of Canada than in the east, hence it was decided to establish the meteor observatories in the west to avoid auroral interference. Suitable sites were found at Meanook and Newbrook, Alberta, giving a base line between stations of approximately 26 miles, lying roughly NW to SE. A magnetic station, in charge of Mr. H. E. Cook, had been operated at Meanook by the Dominion Government since 1916 on leased land. The site chosen for one of the new meteor stations was within 250 feet of this magnetic observatory. Ten acres of land were purchased at Meanook to provide adequate grounds for both the magnetic and meteor programmes, and the operation of this station as a joint magnetic-meteor headquarters has made possible certain administrative economies. More recently the research at Meanook has been expanded to include special auroral and radar programmes connected with the I.G.Y., and the government property has been enlarged to 540 acres in all to afford adequate protection from either optical or magnetic interference.

To set up the station at Newbrook, two acres of land were purchased just south of the town. The geographic co-ordinates of the two meteor observatories, as determined later by the Geodetic Survey of Canada, at the main meteor cameras (Super-Schmidt cameras) are as follows:

Meanook — 54°36′56.″71 N., 113°21′44.″57 W., elevation 2244 ft.
Newbrook — 54°19′26.″66 N., 112°57′15.″22 W., elevation 2205 ft.
Baseline—Meanook to Newbrook, 41.2178 km.

The true bearing of Newbrook from Meanook is close to 142°.

Design and Construction of the Meteor Cameras. The first suggestions for improved meteor camera design involved relatively modest improvements over the existing equipment. It was realized, however, that to reap high dividends in meteor photography a more radical change was necessary and it was decided to adopt a modification of the Television Schmidt camera. The new instrument, called the Super-Schmidt meteor camera, was designed by Dr. James G. Baker, and described by Whipple (1947) in a preliminary outline of the Harvard meteor programme. More complete notes on the camera design have appeared in *Sky and Telescope*, Editorial Note (1951), Whipple (1949).

In brief, the Super-Schmidt combines a wide field in good focus with a very fast effective aperture ratio through the use of two hemispherical

shells of thick glass on either side of a compound correcting plate. The advantage of this system over the conventional Schmidt lies in the fact that the shells, which are spherically symmetrical with the main mirror, correct a large portion of the spherical aberration of this mirror without restricting the field. This means that the conventional correcting plate may be weaker, with a resulting improvement in image quality at the edge of the field.

The Super-Schmidt meteor camera, as designed and built by the Perkin-Elmer Corp. of Norwalk, Connecticut, has an aperture of 12.25 inches and a focal length of 8 inches, giving a nominal aperture ratio of 0.65 and an effective aperture ratio of 0.85. The circular field is 55° in diameter. The film used is molded to a radius of curvature of 8 inches, the emulsion surface is positioned against three focusing lugs to an

FIG. 1—The Newbrook Meteor Observatory looking south. This shows the enlarged observatory as photographed from the radio-communications tower. The glass cupola is used for visual observing in cold weather. A tri-camera spectrograph mount can be seen on the far side of the observatory building.

accuracy of 0.0005 inch, and a two-vane shutter, rotating ⅛ inch above the emulsion, occults the film with a frequency of 60 cycles/sec. The length of occultation is 3 times that of the exposure. A small area, 5 degrees in diameter at the centre of the film, is obscured by the axis of the shutter, and the occulting blades extend out to approximately 2 degrees from the edge of the field.

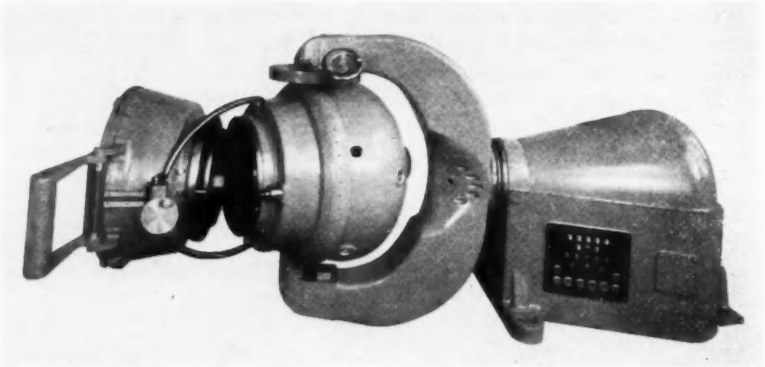

FIG. 2—The mechanical parts of the Super-Schmidt meteor camera, illustrating the way in which the camera is opened for the purpose of changing film.

The mechanical parts of the Super-Schmidts were constructed by the Hartford Special Machinery Co., Hartford, Connecticut. A fork-type equatorial mounting supports the camera proper in which are mounted the 23-inch primary spherical mirror of pyrex glass, the two hemispherical shells—18 inches in diameter, and the compound correcting plate—12.5 inches in diameter. The plate holder is positioned between the correcting plate and the rear shell and supported by the latter. Provision had to be made for opening the camera body to focus the camera and to change film. This operation involves a major redistribution of weight and certain automatic safety features have been built into the mounting so that a film change can only take place with the camera in a position where it will not be thrown out of balance. Camera drive and shutter drive are by synchronous motors. The complete camera and mounting weighs between 5,000 and 6,000 lb., a surprising weight for an instrument of 8-inch focal length.

One of the items which delayed the production of the optical components was the difficulty encountered in securing suitable glass for the hemispherical shells. The requirement was for a borosilicate crown glass

with high transparency in the near ultraviolet, cast in disks approximately 20 inches in diameter and 8 inches thick at the centre. Optical glass of this size had not been cast previously and no commercial glass company was willing to attempt it. At the request of the U.S. Naval Bureau of Ordnance, the Bureau of Standards in Washington agreed to carry out the experimental work necessary, and early in 1951 were able to produce glass of the required specifications. The first Super-Schmidt was completed in May of that year, and put into operation by Harvard in New Mexico, in June 1951 .

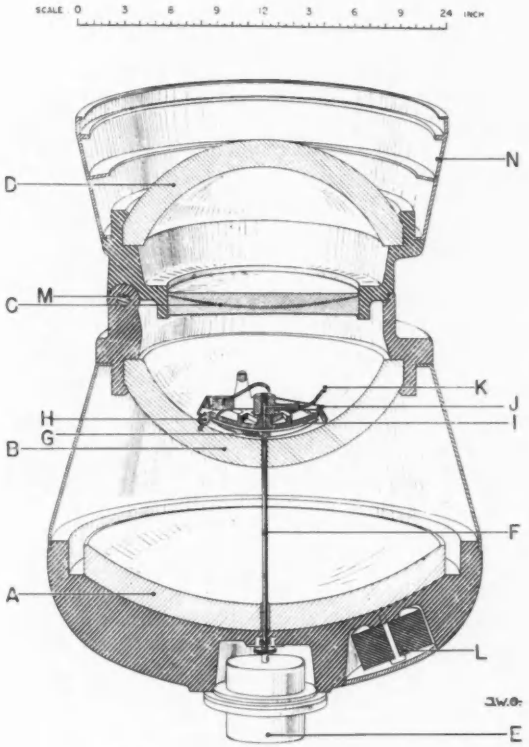

FIG. 3—A cross section of the Super-Schmidt camera. *A* main mirror; *B* rear glass shell; *C* correcting plate; *D* front glass shell; *E* shutter motor; *F* shutter shaft; *G* rotating shutter; *H* focusing post; *I* film holder; *J* film holder hinge; *K* vacuum line; *L* counter weight; *M* hinge for opening camera; *N* dew cap.

In all, six Super-Schmidt meteor cameras were constructed by the Perkin-Elmer Corp. and this company is to be complimented on the successful completion of the project. Problems of a unique nature, both optical and mechanical, had to be solved before an operating unit could be put in the field. The first two cameras completed were assigned to the U.S. Naval Bureau of Ordnance for operation by the Harvard Observatory. The next two were purchased by the Canadian Government for the Dominion Observatory, and the last two were secured by the U.S. Air Force, to be operated in the field by Harvard.

The acceptance field tests of the two Canadian cameras were carried out by the writer at Norwalk between April 29 and May 8, 1952. The optical performance of these cameras proved to be excellent. The images for faint stars had diameters of 30 microns or less over the entire field.

FIG. 4—Glass blanks for the hemispherical shells seen in the Perkin-Elmer shops after preliminary rough grinding.

The bright star images near the edge of the field showed the coma wings typical of highly corrected Schmidt systems, but the percentage of light in these wings was not great and a strong central nucleus was present in all cases. Operating the cameras without shutter and with a dark, moonless sky, maximum possible exposures were 3 to 4 minutes with fast film. For longer exposures, sky fog obscured the faint images. With the rotating shutter, the above exposures can be multiplied by four, since the shutter occults the film for three-quarters of the time.

Delivery of the Cameras and Erection at the Sites. The final adjustment and positioning of the heavy optical parts of the cameras was carried out

at Norwalk. To avoid the jarring which might occur in shipping by rail, the Canadian cameras were flown direct from New York to Edmonton by the Royal Canadian Air Force and then taken by special truck to Meanook and Newbrook. Small buildings, with sliding roof units and suitable reinforced concrete piers, had been constructed at these sites some time before. The two Super-Schmidts were successfully mounted during August

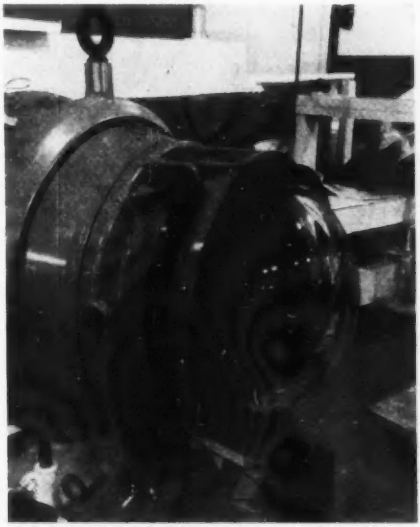

FIG. 5—A completed shell mounted as the front optical element in a Super-Schmidt meteor camera.

1952. First test exposures at Meanook were made on the night of August 15/16 and at Newbrook on August 18/19. During the first exposure at the latter station, a visual meteor of medium angular velocity, estimated by the writer as of magnitude +3.5, crossed the field of the camera. This was recorded as a faint trail on the emulsion and may be taken as indicating roughly the practical lower limit of meteor brightness normally photographed with these cameras.

Outside observing temperatures in Northern Alberta are considerably colder during the winter season than those encountered in New Mexico, where the Harvard cameras were operated. This temperature differential necessitated several cold-weather modifications in the Canadian cameras before they could be operated in the winter months. Heaters were in-

stalled in the shutter motor housing, just below the main mirror, and in the main polar axis housing. These were in addition to the heaters included in the camera design such as those in the dew cap and in the gear box of the main drive. Heat control circuits were modified so that heat could be left on in the cameras continuously during the cold weather, and numerous small adjustments were made in gear spacings and in clutch tensions. Probably the greatest problem was a slight flutter in the rotation speed of the shutter drive shaft. This was present to some extent

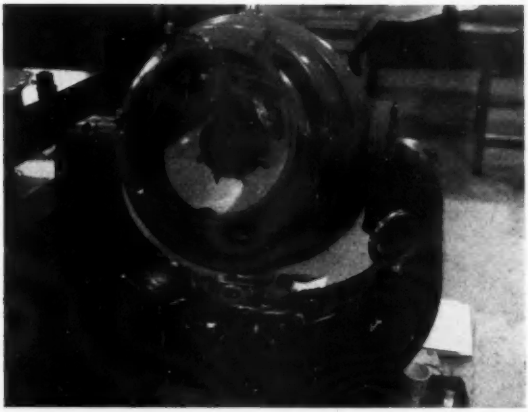

FIG. 6—The rear shell in place, showing the film holder mounted at the centre of the shell. Holes are drilled in the glass shell to provide support for the film holder.

at all times but became particularly serious at very low temperatures. On occasions the shutter motors seized up completely. Careful adjustment of the shutter axis bearings alleviated this trouble to some extent. Experience has shown that it is not profitable to attempt observing with the Super-Schmidt cameras at the lower extreme of winter temperatures, and very few programmes have been carried out with these cameras when the temperature was below −5° F. Only in the case of excellent weather near a shower maximum is observing carried out at lower temperatures.

The primary purpose of a direct meteor photograph taken with a Super-Schmidt camera is to provide accurate co-ordinates for the meteor path, as measured against the star background, and to make possible an accurate measure of angular velocity. A secondary aim is the photometry of the meteor trail to give a light curve along the meteor's path and to provide information about the train or wake. Two photographs of the

same meteor, taken from either end of a suitable base line, make possible the determination of accurate heights, velocities, and decelerations, and a reasonably good estimate of the absolute luminosity at all points on the photographed path. These observed values, when inserted in the equations of the relevant meteor theory, make possible the determination of

FIG. 7—Mounting the camera body at the Meanook Meteor Observatory, August 1952.

the atmospheric density gradients over the range of heights where meteors are visible (Whipple, 1943). It is not sufficient to have the 60-cycle current, used in operating the cameras, maintain a correct average frequency throughout the 24 hours. It must at all times have a frequency correct to within a fraction of one per cent., or a significant instrumental error will be introduced into the computed meteor velocities.

General Radio Vacuum Tube Precision Forks, Type 816 B, were used for the primary frequency control in the Super-Schmidts. Mr. E. L. R. Webb, of the Radio and Electrical Engineering Division of the National Research Council, designed a 100-watt amplifier to feed power from the tuning fork circuit to the camera and shutter motors of the Super-Schmidt.

FIG. 8—The crew which mounted the Super-Schmidt cameras at Meanook and Newbrook. Reading left to right: A. A. Griffin, G. A. Brealey, J. M. Grant, H. E. Cook, J. Pare, A. Page, P. M. Millman.

This amplifier makes use of radio receiver type tubes only, and is described in a report from the above-mentioned Division (ERA-200 by E. L. R. Webb, January 1952).

It had been hoped that, eventually, some of the Super-Schmidt cameras could be operated as meteor spectrographs through the use of Fresnel-type prisms or mosaic gratings. Up to the present, however, experiments along these lines have been unsuccessful, owing to the wide field and unique optical design of the Super-Schmidt. Meteor spectrographs in use at Meanook and Newbrook include Williamson F-24 Aerial cameras equipped with Pentac type lenses of 8-inch focal length and 2.75-inch

aperture, and transmission gratings with a high percentage of luminosity in one order on one side of the direct image. These gratings are made by the Bausch and Lomb Optical Company and the rulings of those used at Meanook and Newbrook range from 80 lines/mm. up to 400 lines/mm. Six of these cameras were originally mounted on two units of the type designed by Webb (1950), and one was located at each observatory some 20 to 30 feet south of the Super-Schmidt piers. These cameras were first put in operation in January 1952, and were originally used without gratings as direct cameras. Gratings were added on three of the cameras in the summer of 1952. A number of faster lenses, and some with longer focal lengths, have recently been mounted as meteor spectrographs. All small cameras regularly operated at the two observatories, now 17 in number, have been converted to meteor spectrographs.

Film Molding Equipment. As noted above, the film used in the Super-Schmidt meteor cameras must be molded to a spherical surface with a radius of curvature of 8.0 inches. The molded film ready for use is a spherical section with a chordal diameter of 7.4 inches. In the camera this is held by vacuum pressure against a spherical metal holder which is then positioned in three focusing lugs that rest on the emulsion surface near its circumference. The equipment and technique for molding film was developed at the Harvard Observatory, following preliminary investigations and suggestions by the Eastman Kodak Co. (Carroll, McCrosky, Wells and Whipple, 1951, 1952). The emulsion found most suitable for direct meteor photography with the Super-Schmidt cameras is the Eastman Kodak single coated blue sensitive X-ray film. This emulsion, with its high relative sensitivity to very short exposures, has been used consistently on the Canadian programme.

The larger basic components for the Canadian film molding equipment were, in general, supplied by the same firms as had constructed the Harvard units. Some of the smaller components were built in the shops of the Dominion Observatory. A film molding room was constructed in the basement of the office building which serves both the magnetic and meteor observatories. The integration and assembly of the various parts of the equipment were carried out by Mr. G. A. Brealey at Meanook. The chief modification introduced in the Canadian film molding equipment was to change slightly the curvature around the circumference of the mold to facilitate the exact positioning of the film in the camera at low temperatures. Under these conditions the film becomes stiff and brittle and its original shape must conform very closely to the required surface, or the vacuum will not have strength enough to pull it tight on the metal holder.

Film storage cans, spacers, and racks for use in transporting and processing the molded film were purchased, following the design of the Harvard equipment described in the Technical Report already referred to (Carroll, McCrosky, Wells and Whipple, 1951). The processed film is stored in boxes of heavy card, two dozen films to the box, the individual exposures being interleaved with soft tissue to avoid scratches.

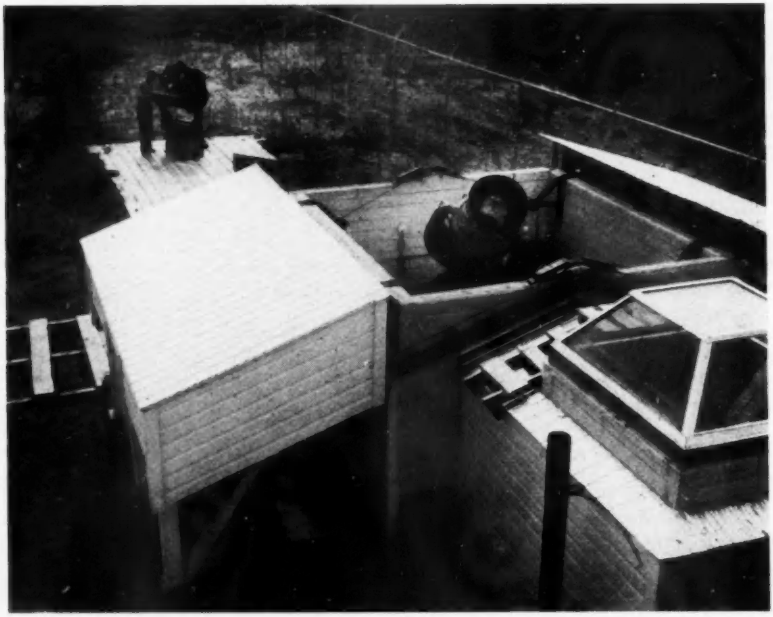

FIG. 9—The Meanook Meteor Observatory, August 1952, showing visual observing cupola in foreground, Super-Schmidt camera centre, and tri-camera meteor spectrograph mounting, rear. Since this photograph was taken the wing including the cupola has been enlarged.

Film Measurement and Reduction. The high curvature of these films raises a problem in their measurement. To avoid a three-co-ordinate measuring technique, it was decided to copy all films containing meteor trails onto glass plates. This not only reduces the problem to one of measurement in two co-ordinates only, but also eliminates possible errors resulting from film changes or deformations during the course of measurement. A special copying lens for the Super-Schmidt meteor cameras was

designed by Dr. Baker and two of these lenses were manufactured by the Perkin-Elmer Corp., one for Harvard and one for the Dominion Observatory. The Canadian lens has been mounted in a copying camera built in the shops of the Dominion Observatory. The design of this camera follows closely that of the copying camera designed and built at Harvard. It is used to copy the spherical surface of the Super-Schmidt film onto a plane surface, giving a magnification of one at the centre of the field. The projection is essentially a gnomonic one, and the measures are normally made on the first copy, which is an eight- by ten-inch glass positive.

The two-co-ordinate measuring machines employed in the reduction of these plates were made by D. W. Mann of Lincoln, Massachusetts, and have been described by Jacchia, Kopal and Millman (1950). The Dominion Observatory purchased one of these instruments in 1953. The early measures and reductions of meteor photographs taken on the Super-Schmidt programme were carried out at the Center of Analysis of Massachusetts Institute of Technology under the direction of Drs. Kopal and Jacchia (Jacchia, 1948). Later Jacchia transferred this work to the Harvard Observatory and modified the reduction system to make use of the I.B.M. "650" calculator. The first group of Canadian photographs has been measured and reduced at Harvard. This arrangement will terminate shortly and in the future the measurement and reduction of the Canadian plates will be carried out in Ottawa.

Reductions made from measures on the Mann machine give the greatest accuracy attainable with the Super-Schmidt cameras in the determination of meteor heights, velocities and decelerations. This accuracy is about one tenth of one per cent. in heights and velocities for the best trails. Two other less accurate procedures have also been used and the various reduction methods, developed at the Harvard Observatory and at the Massachusetts Institute of Technology, have been described in the Smithsonian Contributions to Astrophysics (Whipple and Jacchia, 1957), (Hawkins, 1957), (McCrosky, 1957).

Organization of the Stations. The Meanook-Newbrook meteor observatories are operated as field stations of the Stellar Physics Division of the Dominion Observatory in Ottawa. The writer, as Chief of the above Division prior to January 5, 1955, was responsible for the direction and planning of the meteor programme in Alberta up to that date. In January 1955, Dr. J. L. Locke took over as Chief of the Stellar Physics Division and Dr. Ian Halliday has been placed in charge of the observational meteor programmes of the Dominion Observatory.

Mr. H. E. Cook, Officer in Charge of the magnetic observatory at Meanook, gave very able assistance to the writer in the early planning for the two meteor observatories and in the construction of the necessary buildings. In July 1951, Mr. G. A. Brealey was appointed as Officer in Charge of the Meanook and Newbrook Meteor Observatories. During that same summer Mr. A. A. Griffin and Mr. J. M. Grant joined the staff

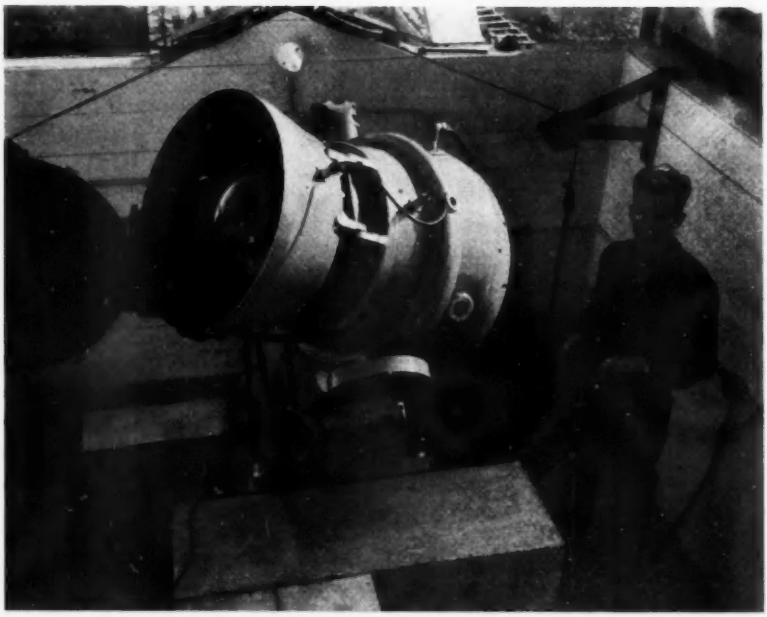

FIG. 10—The Super-Schmidt camera mounted at the Newbrook Meteor Observatory, August 1952. Counter weights at rear are to balance the sliding roof sections.

to assist Mr. Brealey in carrying out the meteor programme at the new stations. In May 1954, Mr. Brealey transferred to the Division of Positional Astronomy of the Dominion Observatory and returned to Ottawa, and Mr. Griffin was appointed to take charge at the meteor observatories. At the same time Mr. Dennis Corness joined the staff to maintain the strength of personnel engaged in the meteor work. In the summer of 1957, Mr. Corness left to continue his post-graduate studies and was replaced by Mr. T. E. Chmilar. Mr. Cook retired from his position at the magnetic observatory in June 1957.

Since suitable living accommodation for the staff was unavailable in

the neighbourhood of either of the meteor observatories, residences were built at both Meanook and Newbrook to house the meteor personnel. The residence at Meanook was completed and occupied in October 1951, and that at Newbrook in November 1952. In the fall of 1953, both meteor observatory buildings were enlarged to provide better facilities for operating the Super-Schmidt cameras and the meteor spectrographs. In 1956–57, the office building at Meanook was enlarged, thus providing better dark room and office space for both the magnetic and meteor programmes.

FIG. 11—A Newbrook Super-Schmidt photograph (SN 1682) showing the handle of the Big Dipper at right and the bowl of the Little Dipper above centre. This 13-minute exposure started at 09.00 hrs U.T. on April 22, 1957. The faintest stars appearing on this negative are of about the 14th magnitude. A bright Lyrid meteor was photographed at $9^h\ 12^m\ 24^s$ U.T. The interrupted trail of the meteor is seen at bottom.

The meteor observatories originally operated on local electric power systems and this created serious difficulties in maintaining the required accuracy in the frequency supplied to the Super-Schmidts. However, in September 1952, power from Northland Utilities at Athabaska was made available at Meanook and in December 1954, Calgary Power extended their lines to Newbrook. Since then, no serious power difficulties have arisen. Communication between Meanook and Newbrook by telephone is unreliable and inefficient. Contact between the two observatories is maintained through a 30-watt Rogers Majestic frequency modulated radio communications system (Model CFS TRU-80BR), working at 153 mc./sec. The mattress-type aerials are mounted on 50-foot towers, and the serviceability of this installation has been very good.

Weather Conditions and the Observing Programme. The general weather conditions prevalent in northern Alberta are not favourable for astronomical observation. Apart from the severe cold in winter a large percentage of the nights are cloudy or partially cloudy. Quite frequently brilliant aurora makes it impossible to operate fast cameras. During June and July no observing is practical because of twilight conditions throughout the night. Meteor observing at Meanook and Newbrook is not normally planned when a bright moon is in the sky. On the average, some 25 nights per month are scheduled for meteor observation in January and December, and between 20 and 23 per month in February, March, April, September, October, and November. A somewhat smaller number are scheduled for May and August, and none in June and July. In Table I

TABLE I

NUMBER OF NIGHTS WHEN METEOR PHOTOGRAPHY WAS CARRIED OUT AT MEANOOK AND NEWBROOK

Month	Year				Average Number of Nights	Percentage of Nights worked for Nights Scheduled
	1954	1955	1956	1957		
January	0	6	1	1	2	8%
February	0	5	0	1	1.5	7
March	5	3	2	2	3	13
April	2	2	6	4	3.5	18
May	0	0	6	0	1.5	23
August	10	12	10	7	10	63*
September	8	3	3	3	4	22
October	5	7	9	2	6	25
November	6	2	7	2	4	19
December	9	0	3	8	5	20
Totals	45	40	47	30		

*The very high percentage found in August is in part due to the fact that near the Perseid maximum observations are often attempted even if the conditions are not good.

are listed the number of nights in each month during which some exposures were made for the four years from 1954 to 1957. In the last two columns are given, for each month, the average number of nights worked and the percentage of scheduled nights on which some photographic work was possible. The four-year average shows 40 nights worked per year out of a possible 200 scheduled for meteor observation. In other words, just 20 per cent. of the scheduled nights are suitable for observation. It is not surprising that the gathering of meteor data with the Canadian cameras has been much slower than in the case of the American instruments. The latter are operated in New Mexico where, on the average, 130 nights per year are suitable for meteor photography.

The completion of the film molding unit and the cold weather modifications and adjustments of the Super-Schmidt cameras prevented their regular use on the systematic programme during the winter of 1952–53. The first paired photographs were taken in May of 1953. Regular observing was again interrupted for some months during the fall of this year, owing to the enlargement of the meteor observatory buildings. The full-scale programme of observation cannot be considered to have commenced until 1954. By the end of 1957 some 1800 pairs of exposures had been made with the two Super-Schmidt cameras, the normal exposure being 12 minutes in length. These two series of photographs are designated SM for the Meanook Super-Schmidt and SN for the Newbrook Super-Schmidt. Approximately 340 hours of observation were carried out with each instrument. During this time some 600 meteor photographs were secured (including 165 paired photographs), an overall rate of one meteor photograph for every 60 to 70 minutes of exposure time. The Harvard cameras in New Mexico have yielded about one meteor for every 15 minutes of exposure time. The difference between the Canadian rate and that found in the U.S.A. may be attributed chiefly to the poorer observing conditions at the Canadian stations. These conditions include lower atmospheric transparency, intermittent clouds, interference from twilight and aurora, and reduced film performance owing to low temperatures.

Over 8,000 exposures were made with the meteor spectrographs at Meanook and Newbrook up to the end of 1957, exposures varying from 20 to 60 minutes. Forty-one meteor spectrum photographs were secured at the two observatories. These are tabulated regularly in the world list of photographic meteor spectra (Millman, 1957) and six have been described in some detail (Millman, 1956), (Halliday, 1957, 1958). The staff at Meanook and Newbrook carry out a visual watch for meteors whenever this is possible during the time the meteor cameras are exposed.

In the six-year period, 1952 to 1957 inclusive, 3,800 meteors were visually recorded at the two stations.

It is of interest to note here that, within a few months of the establishment of the Newbrook Meteor Observatory, the largest Canadian meteorite that has been seen to fall landed at Abee, just 8 miles south of the Observatory, at 06.05 hours U.T., June 10, 1952 (Millman, 1953). Thanks to the initiative of Mr. Griffin, who was stationed at Newbrook, the owner of the land on which the meteorite fell was approached. Later in the summer, the writer was able to arrange for the purchase of this meteorite by the Geological Survey of the Department of Mines and Technical Surveys in Ottawa.

It may also be noted that at Newbrook on October 9, 1957, at 11.52 hrs. U.T., Mr. Griffin secured the first photograph of the satellite 1957 α 1 taken on the North American Continent. During the International Geophysical Year, the staff at Meanook are assisting in the Canadian auroral programme by operating an all-sky camera, a patrol spectrograph and an intensity recorder.

Acknowledgements. In concluding this account of the establishment of the two meteor observatories in Alberta, I should like to record a hearty vote of thanks to all those institutions and individuals who gave so freely of their time, and helped out when difficulties arose. In particular, I should mention the assistance of the Naval Bureau of Ordnance and of the Glass Section of the National Bureau of Standards in Washington, and of the Royal Canadian Air Force in Ottawa, in making possible the purchase of the optical glass required for the shells; the assistance of the National Research Council in the problem of high precision frequency control; the courtesies extended by Mr. G. Wallace, Mr. J. Vrabel, and other members of the Perkin-Elmer Corporation; the help in testing the Canadian cameras given by Dr. R. E. McCrosky of the Harvard Observatory; consultation with Dr. Z. Kopal and Dr. L. Jacchia at M.I.T.; the invaluable advice and assistance given by Dr. F. L. Whipple and his staff, both at the Harvard Observatory and at the field stations in New Mexico; numerous consultations and visits with Mr. R. G. Madill, Chief of the Division of Terrestrial Magnetism at the Dominion Observatory, and with Mr. H. E. Cook, Officer in Charge of the Meanook Magnetic Observatory; the loyal support and industry of the staff at Meanook and Newbrook; and finally the constant helpful discussions with, and encouragement, of the late Mr. R. Meldrum Stewart, and of Dr. C. S. Beals, the two Dominion Astronomers under whom the work was carried out.

References

Carroll, P., McCrosky, R. E., Wells, R. C. and Whipple, F. L. 1951, *Harvard College Obs., Tech. Rep.* no. 8; 1952, *Photographic Science and Technique, Section B of P.S.A. Jour.*, vol. 18, no. 3, p. 14.

Halliday, I. 1957, *Jour. Roy. Ast. Soc. Canada*, vol. 51, p. 287; 1958, *Ap. J.*, vol. 128, p. 441.

Hawkins, G. S. 1957, *Smithsonian Contr. to Astrophysics*, vol. 1, p. 207.

Jacchia, L. G. 1948, *Harvard College Obs. and Center of Analysis of Mass. Inst. Tech., Tech. Rep.* no. 2.

Jacchia, L. G., Kopal, Z. and Millman, P. M. 1950, *Ap. J.*, vol. 111, p. 104.

McCrosky, R. E. 1957, *Smithsonian Contr. to Astrophysics*, vol. 1, p. 215.

Millman, P. M. 1932, *Harvard Ann.*, vol. 82, p. 113; 1935, *Harvard Ann.*, vol. 82, p. 149; 1953, *Jour. Roy. Ast. Soc. Canada*, vol. 47, pp. 29, 92, 162; 1956, *Sky and Telescope*, vol. 15, p. 375; 1957, *Jour. Roy. Ast. Soc. Canada*, vol. 51, p. 351.

Sky and Telescope, Editorial Note, vol. 10, p. 219, 1951.

Webb, E. L. R. 1950, *Jour. Roy. Ast. Soc. Canada*, vol. 44, p. 110.

Whipple, F. L. 1943, *Rev. Mod. Physics*, vol. 15, p. 246; 1947, *Harvard College Obs., Tech. Rep.* no. 1; 1949, *Sky and Telescope*, vol. 8, p. 90.

Whipple, F. L. and Jacchia, L. G. 1957, *Smithsonian Contr. to Astrophysics*, vol. 1, p. 183.

CANADIAN SCIENTISTS REPORT-XIV

GEOLOGICAL TIME

By R. M. Farquhar
University of Toronto

In recent years much effort has been directed by geophysicists and geologists to the study of subjects of mutual interest both to earth-scientists and to astronomers. One aspect of these studies is the measurement of *time* in the earth's history. Geophysicists and geologists are, of course, acutely interested in measuring time intervals and the dates of various events which took place in the distant past because these dates make possible the determination of the rates at which various earthly processes have taken place. Astronomers share this interest, since the early stages of the earth's development are closely tied to that of the entire solar system.

All the methods for the accurate determination of time intervals and the dating of various events in the earth's history are based on the radioactive decay of a few naturally occurring isotopes. These same decay processes have supplied much of the internal heat of the earth and hence are responsible in part for the changes in the earth's surface features which have occurred since the outer part of this planet solidified. These isotopes, uranium 238, uranium 235, thorium 232, rubidium 87, potassium 40 and a few others are slightly unstable and decay extremely slowly to form new stable products. If one or more of these radioactive elements are concentrated in a rock or mineral at the time of its formation, the stable end product will slowly accumulate there, the ratio of product to parent increasing as time goes on. The value of this ratio at the present time is a measure of the length of time over which the accumulation has taken place, assuming that the rate of decay of the parent isotope is known. We must also assume that no changes in the ratio have taken place other than that due to radioactive decay, and that we can account for and subtract any of the product isotope deposited with the mineral at the time of its formation. For example, the uranium isotopes and thorium 232, decay to stable lead isotopes, and consequently the measurement of the uranium, thorium and accumulated lead in an igneous rock or mineral should make it possible to estimate the time at which the

rock or mineral solidified. This method was one of the first to be developed and has been applied to determine the ages of a great many rocks and uranium minerals.

The determination of such ages is an endeavour which has developed rather slowly into an important branch of the earth sciences. Canadian scientists have taken an active part in this development from its beginning and have been among the first to realize the importance of the results in determining the length of geological periods. Age determination studies are, at present, being undertaken at two universities in Canada (Universities of Toronto and Alberta) and by the Geological Survey of Canada in Ottawa.

Canadian workers in the field of absolute age determination are fortunate in that they are geographically close to the great area of the Canadian Precambrian Shield, a region of ancient rocks whose structure is so complex that age determinations appear to provide the only positive key to the unravelling of its history. The work that has been done up to

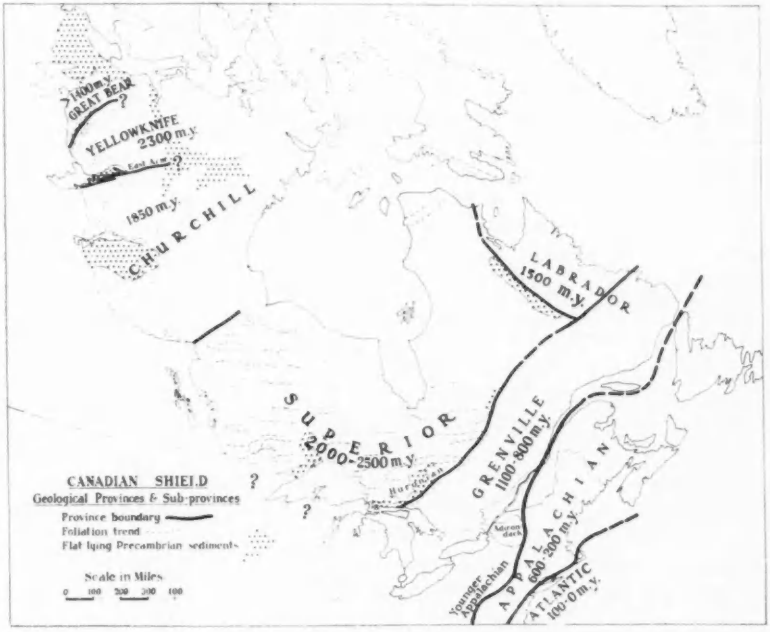

FIG. 1—Map of Canada showing ages of rocks in different areas, as determined from radioactive minerals.

the present has made possible only the dating and sub-division of the major segments of the Shield but the results already have been of considerable importance to theories concerning the growth of continents during geological time and the general problems of the sub-division and classification of very ancient rocks. These major divisions for Canada are shown in figure 1. As this figure shows, the Shield is composed of areas

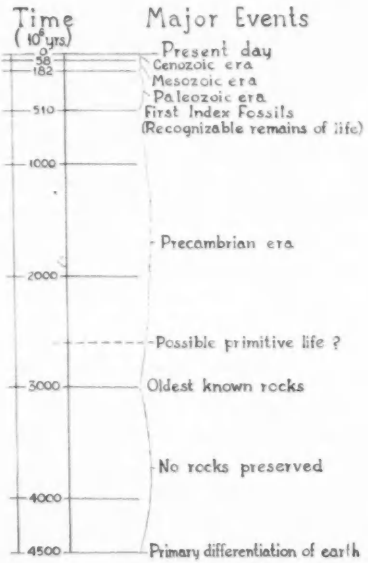

FIG. 2—Geological Time Scale indicating some major events in the earth's history, and the times at which they occurred.

containing rocks of very different ages. The great expanse of time covered by the rocks of the Shield is one of the surprising facts which has come from age determination studies. It has become apparent that Precambrian time has occupied a far greater proportion of the earth's history than was previously suspected. Similar conclusions have resulted from age determinations made on rocks from other continents.

Apart from the purpose of sub-dividing and classifying rocks age determinations are useful for the construction of a time scale in which geological events may be ordered both on a local and world-wide basis. Here again only the major divisions have been determined for the various continents. There is general agreement on the times at which

the major eras in the geological time scale began and ended. These eras were defined by stratigraphers and paleontologists long before their true or absolute lengths were estimated. The age determinations have simply enabled geologists to view the parts of this relative time scale in proper proportion. The major units of this scale are shown in figure 2. A few of the sub-divisions given in this figure are worth noting in more detail. The first is the time at which organisms developed sufficiently resistant forms to leave clearly recognizable traces in the sedimentary strata where they were buried. This occurred about 500 million years ago and this date marks the beginning of the Cambrian period.

The rocks which were formed before the Cambrian occasionally contain objects which are believed (although not definitely proved) to be traces of simple life. Until recently it was impossible to estimate the ages of these remains simply because there were no data on the ages of the rocks in which they were found. In 1956, however, one example of these early evidences of life was found in South Africa beneath rocks dated at 2,700 million years and therefore must be as old as or older than this. If this structure is definitely the remains of organic material, then life has existed on this planet far longer than was suspected a few years ago.

As the quantity of age determinations increases, it might be expected that older and older rocks would be discovered leading back in an unbroken sequence to the beginning of the earth. This is not the case. As figure 2 shows, the oldest surface rocks which have been discovered are about 3,000 million years old and at present there seems little prospect of discovering any older than this. There is a gap of 1,500 million years between the earliest preserved rock and the time at which the chemical differentiation of the earth into nickel-iron core and silicate mantle took place. The most probable explanation for this hiatus seems to be that the surface of the earth was simply too hot during that period to permit the formation or preservation of any rocks. We are faced with the possibility of the existence of a very long period for which there is no record remaining in continental surface rocks.

The time at which the major chemical differentiation of the earth took place is one of the most accurately dated events in the earth's history. Oddly enough, this figure of 4,500 million years has been determined from measurements of the isotopic constitution of the lead in iron meteorites, rather than from analysis of samples of terrestrial origin. Iron meteorites contain such small amounts of uranium that the isotopic composition of the lead in them has remained essentially unaltered throughout their lifetimes. We then assume that the isotopic composi-

tion of the meteoritic lead is identical to that of the lead which existed in the earth before the differentiation process occurred. This process concentrated most of the earth's uranium in the outer part of the planet. Lead ore deposits, formed subsequently in the crust, have isotopic compositions which have been considerably altered because of additions of lead produced by the decay of this uranium. In this sense the outer part of the earth is like a uranium mineral; knowing the isotopic composition of the lead originally present in it, we can calculate how much has accumulated since its "birth" and thus calculate a value for that time.

The major divisions of the time scale are fairly clear. What remains at present is to attempt to sub-divide the various periods in it and apply the techniques which have been developed to the solution of particular geological and geophysical problems. Experience has shown that far from being routine these problems will provide us with fascinating studies of natural physical and chemical processes that have occurred on earth in the past, as well as giving us valuable information about the times at which these processes took place.

VARIABLE STAR NOTES

By Margaret W. Mayall
The American Association of Variable Star Observers

On October 5, 1957, the first Sputnik was successfully shot into its orbit around the earth, and the members of the A.A.V.S.O. were holding their 46th annual meeting. On October 11, 1958, the lunar probe, Pioneer, was sent out about 80,000 miles from the earth, and the members of the A.A.V.S.O. were holding their 47th annual meeting. The 48th annual meeting will be held during the week-end of October 2, 1959 in the greater Boston area. The expected event for that meeting is the sunrise solar eclipse, but we wonder what else there will be.

The 1958 meeting was held at the Natural History Museum in Springfield, Massachusetts, at the kind invitation of the Director, Mr. Frank D. Korkosz. The meeting opened with a talk by the Mayalls on their recent trip to Russia to attend the International Astronomical Union meeting in Moscow. They showed many colour slides illustrating the rapid developments taking place in the U.S.S.R. The talk was followed by a demonstration of the Seymour Planetarium by Mr. Korkosz.

At the business session, the following officers were elected for the year 1958–1959: President, Ralph N. Buckstaff; 1st Vice-President, Edward G. Oravec; 2nd Vice-President, Dorrit Hoffleit; Secretary, Clinton B. Ford; Treasurer, Percy W. Witherell; Director, Margaret W. Mayall; Clerk, R. Newton Mayall; and Auditor, Cyrus F. Fernald. The Council for the year is composed of the following: George Diedrich, Charles M. Good, Sarah J. Hill, Dorrit Hoffleit, Edward G. Oravec, John E. Welch, Peter M. Millman, and John J. Ruiz.

The Council took great pleasure in electing Mrs. Walter P. Reeves a Patron member, as a slight token of appreciation for all she and her late husband have done for the Association. Twenty annual members were elected at this meeting, as follows: Mary Callahan, *Michigan*; Jon Canaday, *Oklahoma*; Theodore L. D'emmon, *Connecticut*; James E. Ellerbe, *Bierut, Lebanon*; Richard S. Harman, *West Virginia*; Casper H. Hossfield, *New Jersey*; Orin H. Kindt, *Wisconsin*; Toribio Martinez C., *Celaya, Gto., Mexico*; William G. Mebius, *New Jersey*; Norman Olsen, *New York*; Alexander K. Presnell, *Ohio*; Robert Rosalsky, *New Jersey*; Gordon W. Smith, *Ancaster, Ont., Canada*; Robert H. Teese, *New Jersey*; James E. P. Toman, *Illinois*; David I. Tonkin, *California*; Miguel Valdez, *Santiago, Chile*; Albert Ullman, *New York*; S. H. Wolfe, *North Carolina*; and Dean S. Wood, *California*.

The Director's report showed that a total of 51,317 observations from 143 observers was received during the fiscal year. Fifteen countries outside the U.S.A. were represented. The order of the 3 observers at the top of the list of number of observations made during the year has remained the same for 3 years: this year, Reginald P. de Kock made 5,983 observations, Edward G. Oravec, 4,686, and Cyrus F. Fernald, 4,374. The next highest, with more than 1,000 observations each, were, in order: Rudolph, Anderson, Cragg, Adams, Ford, Hartmann, Taboada, Renner, Allin, Rosebrugh, and Peltier.

We were very pleased to have 40 new observers start work during the year. Among them, Robert Allin of the Edmonton Centre should be mentioned. He sent his first report of 3 observations of 3 variables in February, continued increasing his programme each month until he had over 200 observations of about 50 variables (1,101 observations for the year), and joined the ranks of the "Inner Sanctum" by observing stars fainter than 13.8 magnitude. Twenty-five other observers made "Inner Sanctum" observations.

The most exciting variable star event of the year was the discovery of the 3rd maximum of the recurrent nova RS Ophiuchi, by Cyrus Fernald. It was also discovered independently by David Rosebrugh, Reginald de Kock, Leslie Peltier and others. The light curve of the current maximum is almost an exact duplicate of that of the 1933 maximum and helps confirm the assumption that the star was about 20 days past maximum when it was observed in 1898. The promptness of Mr. Fernald in reporting his discovery permitted astronomers on the West Coast to obtain spectra of it the same night.

Photoelectric observations of RS Ophiuchi were received from 2 of our new observers: Donald Engelkemeir of Hinsdale, Illinois and Allan Sandage of Mount Wilson Observatory. Several observations were made near the same time with the Mount Wilson 100-inch reflector and Engelkemeir's 8-inch reflector, and they agreed within a few hundredths of a magnitude.

The broad maximum of 1957–1958 of Mira Ceti was recently reproduced in these Notes. (See this JOURNAL, vol. 52, no. 5, p. 236.) When the star reappeared in the morning sky in May, soon after the predicted minimum, it was about 1 magnitude brighter than the mean minimum value, and started to rise rapidly to a very narrow bright maximum, about 3rd magnitude, the first of October.

A strong influence of the International Geophysical Year was evident in many of the papers presented at the meeting. Reports on the following papers are published in the A.A.V.S.O. Abstract series: *Light Curves of Mira and RS Ophiuchi*, Margaret W. Mayall; *After the I.G.Y., What?*, George Diedrich; *Sun-spots on the Same Meridan*, Ralph N. Buckstaff; *Aurora Photography And Spectroscopy*, Walter A. Feibelman; *Variations in Radio Atmospherics*, Philip J. Del Vecchio; *Photographic Observations of RS Ophiuchi*, Margo Friedel and Andrea R. Kundsin; *Determining The Heights of Auroral Displays*, Francis H. Reynolds; *The Regular Red Variables*, Thomas A. Cragg; *Magnitude Peaks Of The Sputniks*, Philip Seldon; *A Test Of The Seeing*, Gunnar Darsenius; *Some Early French Astronomical Prints*, Albert Ullman; *Brightness And Magnitudes Of Some Very Bright Stars*, Herbert A. Luft; *Fernwold Observatory*, Cyrus F. Fernald; *Solar Photography*, Walter J. Semerau; *S.E.A. Sidelights*, David D. Warshaw; *Recording Sudden Enhancement Of Atmospherics*, Harry L. Bondy.

A.A.V.S.O. Nova Search Report (From George Diedrich, Chairman):

Observations of Nova Search Areas were made by the following 14 observers for a total of 229 area-nights. Each name is followed by the number of observations made in August and then September, 1958: Robert M. Adams–0, 3; Richard Bates–10, 7; James Breckinridge–11, 0; Harley Decker–6, 10; Frank J. DeKinder–15, 14; DeLorne Diedrich–8, 4; George Diedrich–8, 11; Kenneth Fuller–0, 13; Geoffrey Gaherty, Jr.–16, 12; William Isherwood, Jr.–0, 5; John Morrison–9, 9; I. K. Williamson–6, 6; James F. Wesling–6, 8; K. Zorgo–17, 15.

A description of the 2nd Edition of the *General Catalogue of Variable Stars*, by B. V. Kukarkin, P. P. Parenago and their associates, continued from the last of these Notes, follows:

The second volume contains a most useful collection of key tables to aid in locating variables in the first volume from any published name or identifying number.

The first table contains a list of all variables arranged according to the type of variation, followed by lists of erroneously designated and non-existing variables. A table of novae gives preliminary and final designations and names of discoverers.

In order to facilitate identification of newly discovered variables, all variables from the first volume are arranged accordng to their 1900 positions in the next table.

More than 300 pages are devoted to a group of 21 tables which list the variables according to every possible form of nomenclature. The first part gives for each variable in a constellation all known designations, and the following 20 tables are cross references.

The last part of the volume contains a table for conversion of hours and minutes of time to 4-place decimals of a day, and a table of Julian Days for each month from 1850 to the year 2000. These tables are preceded by a table for the transition from the generally accepted Argelander system of variable star designations (R, S, T, etc.) to the system in which variables are designated by the letter V, followed by the number of the variable in the constellation, followed in turn by the abbreviation of the constellation. This system may become more necessary as punch card methods come into more general use. The number system has been in use in constellations where the letters were exhausted. For instance, QZ Cygni is followed by V335 Cygni. In the future R Cygni may be called V1 Cygni, and SS Cygni will become V19 Cygni.

The authors of this second edition of the *General Catalogue of Variable Stars* are certainly to be congratulated for the exceedingly fine and painstaking work they have done. They are very generous in the credit they give to astronomers all over the world for their co-operation on the project. The Introduction to the catalogue ends with the following: "We are quite sure that the international collaboration of astronomers in the domain of variable star studies will be strengthening and developing and will serve as a contribution in the consolidation of peace in the whole world."

Observations received during September and October, 1958. In September, 80 observers contributed 5,695 observations, and in October, 76 sent 5,640 a total of 11,335 for the two months.

Observer	Sept. Var.	Sept. Ests.	October Var.	October Ests.
Adams, R. M.	82	142	62	140
Allin, R.	49	229	30	67
Anderson, C. E.	223	462	243	503
Anderson, E.	..	..	1	1
Bales, R. M.	4	4	4	9
Ball, A. R.	14	14	..	..
Bartha, L.	..	..	6	24
Beidler, H. B.	12	12	4	4
*Berg, R.	8	30	20	40
Bicknell, R. H.	13	97	..	..
Bieda, S. W.	4	14	..	..
Bohannon, B.	3	3	1	3
Breckinridge, J.	35	68	33	40
Buckstaff, R. N.	10	24	..	..
Byrd, W.	..	..	10	13
Carlisle, J. H.	1	2	..	..
Carpenter, C. B.	10	10	43	43
Cragg, T. A.	133	159	377	406
†Darsenius, G.	16	79	8	24
Diedrich, DeL.	4	8	2	6
Diedrich, G.	6	13	6	11
Diedrich, P.	..	..	13	13
***Engelkemeir, D.	7	20	5	10
Erpenstein, O. M.	9	10	13	30
Fallon, F. W.	1	1	..	..
Fejes, M.	..	..	6	57
Fernald, C. F.	226	756	293	809
Fletcher, D. M.	..	..	5	5
Ford, C. B.	199	211	152	157
Fuller, K.	23	23	53	63
Gauser, M.	..	..	5	17
Gemberling, R. H.	37	67	..	..
Glenn, W. H.	19	29	..	..
Godfrey, N. B.	35	37	14	14
Goodsell, J. G.	4	4	2	2
Halbach, E. A.	9	9	6	6
Halvorson, D. O.	..	..	12	26
Hartmann, F.	143	166	155	168
Hein, G. J.	2	2	..	..
Hiett, L.	..	..	6	13
Hunter, T.	..	..	1	1
Hutchings, N. O.	15	24	11	11
Kelly, F. J.	13	13	11	11
Kindt, O. H.	3	3	4	4
Knowles, J. H.	12	19	..	..
de Kock, R. P.	135	647	138	693
Koons, L. D.	10	25	8	13
Kubanoff, J. H.	2	2	3	6
Lacchini, G. B.	78	188	76	246
Lattey, M.	4	13	7	15
Lowder, W. M.	62	151	55	107
Luft, H. A.	3	8	..	..
Magruder, R. S.	5	5	9	12
McGovern, R.	9	9	..	..
McPherson, C. A.	50	58	50	57
Mebius, W. G.	14	29	..	..
Melville, E. C.	..	..	10	10
Miller, R. W.	12	12	13	13
Miller, W. A.	5	8	13	14
Mojsza, M.	..	..	3	3
Montague, A. C.	22	32	32	43
Morgan, F. P.	9	20	13	33
Oravec, E. G.	219	435	179	382
Overbeek, M. D.	82	201	..	..
Parker, P. O.	24	98	33	47
Pearcy, R. E.	3	5	4	4
Peltier, L. C.	23	156	24	131
Peters, P.	..	..	14	19
Pinter, M.	..	..	1	1
Ponory, M.	..	..	1	1
Price, F. J.	29	56	19	33
Renner, C. J.	233	233	..	..
Rizzo, P. V.	14	20	7	12
Robinson, J. C.	15	18	14	21
Robinson, L. J.	3	7	67	181
Rosalsky, R.	..	..	1	1
Rosebrugh, D. W.	11	114	12	104
Rosenblatt, F.	5	5	..	..
Rosenfield, C. C.	30	54	1	1
Royer, R.	4	6	..	..
Sandage, A.	1	10	..	..
Schultz, G. W.	1	1	..	..
Segers, C. L.	31	55	21	42
Silveira, W. M.	3	4	4	3
Skaritka, P.	48	60	121	170
Smits, P.	37	62	39	77
Solomon, L.	2	2	15	13
Szanta, M.	..	..	3	5
Szekely, M.	..	..	6	64
Taboada, D.	..	..	32	39
Thaly, M.	..	..	6	79
Thomas, M. A.	5	14	..	..
Thurn, V. W.	11	12	..	..
Tsai, C. H.	..	..	19	43
Valdez, M.	1	1	1	1
Venter, S. C.	..	..	59	149
Wallerstein, G.	14	21	..	..
Weitzenhoffer, K.	4	4	..	..
Wend, R. E.	5	5	1	1
Whidden, G.	3	5	..	..
Wilson, J.	4	4	..	..
Wyckoff, J.	20	56	..	..

*Plus 2^h 59^m AE Aqr †Plus 28^m DO Cep; 55^m EV Lac ***Plus 16^m *PEP*, RS Oph

NOTES FROM OBSERVATORIES

David Dunlap Observatory, Richmond Hill

Among Canadian delegates to the Tenth General Assembly of the International Astronomical Union in Moscow during the summer of 1958 were four from this Observatory: Dr. Helen Hogg, Dr. Donald A. MacRae, Miss Ruth Northcott and Dr. Sidney van den Bergh.

During the autumn, several astronomers from other observatories spent some time here, engaging in research programmes. Dr. William Buscombe of Mount Stromlo Observatory, Canberra, Australia, spent three months assisting in the Department of Astronomy, and studying the radial velocities of B-type stars; Dr. Sarah Hill of Wellesley College, Mass., spent six weeks in the study of velocities of several spectroscopic binaries; Dr. William Wehlau of the University of Western Ontario and Dr. J. Allen Hynek of the Smithsonian Astrophysical Observatory each spent several days here studying the Observatory's collection of stellar spectrograms in connection with investigations in which they are interested.

The writer attended the meeting of the American Astronomical Society in Madison, Wis., in July.

Graduate students in the Department of Astronomy this session include Messrs Gustav Bakos, Pierre Demarque, David Hogg, Loren Linstrom, Stephen Morris and Duncan McNeill. Mr. Hogg, a graduate of Queen's University, holds a National Research Council studentship and Mr. Demarque is the first holder of the C. A. Chant Fellowship, recently established under the terms of Dr. Chant's will.

Mrs. Margaret Lamb, Secretary at the Observatory during the past three years, has resigned her position to return to England. Mrs. Nancy McKenzie of Richmond Hill has been appointed to the position.

John F. Heard

NOTES

Dome Built by Ancaster Member

The photograph shows the observatory which I have just completed. The dome has been made from Tee sections and aluminum sheet. It revolves on twelve roller-skate wheels and is 8 feet in diameter. I designed and built it to house my 4-inch Unitron refractor.

To build a small observatory like this may not be exceptional, but what may be exceptional is that it cost less than $200. I may add that no specialized skill was required: I am a salesman and had no previous knowledge of metalwork.

The benefits from having a building for even a small telescope are numerous and the pleasure of observing is greatly increased. I can heartily recommend the project to others.

Gordon W. Smith

Enquiries concerning details of construction will be forwarded to Mr. Smith by the Society's National Office.

REVIEW OF PUBLICATIONS

Stellar Populations edited by D. J. K. O'Connell, S. J. Pages viii plus 544, 6¼ × 9¼ in. Amsterdam, North Holland Publishing Company (New York, Interscience Publishers Inc.) Price $10.00.

This volume contains the proceedings of the conference week on stellar populations organised by the Pontifical Academy of Science at the Vatican Observatory, May 20–28, 1957. The conference was attended by: Baade (Mount Wilson), Blaauw (Groningen), Chalonge (Paris), Fowler (Pasadena), Heckmann (Hamburg), Herbig (Lick), Hoyle (Cambridge), Lindblad (Stockholm), Morgan (Yerkes), Nassau (Cleveland), O'Connell (Vatican), Oort (Leiden), Salpeter (Ithaca), Sandage (Mount Wilson), Schwarzschild (Princeton), Spitzer (Princeton), Strömgren (Princeton) and Thackeray (Pretoria), Lemaître (Liège).

The central theme of the conference was the stellar content of galaxies and its relation to stellar and galactic evolution. The discussions clearly revealed the inadequacy of a rigid division of all stars into two populations. The classification of stellar populations, which is given in the table below, was adopted by the conference.

CLASSIFICATION OF STELLAR POPULATIONS

Halo population II: Globular clusters, RR Lyrae Stars with periods longer than 0.4 days, Subdwarfs.

Intermediate population II: High-velocity stars, long-period variables with periods shorter than 250 days.

Disk population: Stars of the galactic nucleus, Planetary nebulae, novae, RR Lyrae stars with periods shorter than 0.4 days, weak line stars.

Old Population I: A-type stars, strong line stars.

Extreme Population I: Bright young stars, T Tauri stars, Cepheids.

The observational data presented during the conference suggest that a further subdivision of population types will probably be required. This was particularly evident for the halo population II stars. The well-observed globular clusters seem to form a sequence ranging from those with extreme metal deficiencies (M 92) to those with only moderate metal deficiencies (M 3). Observations of the colour-magnitude diagram of a dwarf elliptical galaxy in Draco by Baade suggests that its consti-

tuent stars are even more deficient in metals than those of M 92. On the other end of the sequence globular clusters appear to exist with metal abundances not much lower than those encountered in the sun. An investigation by Morgan of the integrated spectra of globular clusters revealed a number of these relatively metal-rich objects in the direction of the galactic centre. Unfortunately no accurate colour-magnitude diagrams exist yet for any of these clusters. Thackeray presented evidence suggesting that 47 Tuc may be such a cluster.

Baade's work on the Draco system makes it highly probable that dwarf elliptical galaxies contain a stellar population similar to globular clusters. The composition of giant ellipticals and of the nuclei of spiral galaxies is however still in doubt. The integrated colours of giant elliptical galaxies are similar to those of the dwarf ellipticals. In both types of systems the brightest stars have approximately the same absolute magnitude. However, the integrated spectra of giant ellipticals and of the nuclei of spiral galaxies show no evidence of weakness of the metal lines. This suggests that the bulk of their stellar population is not similar to that of normal globular clusters. However, it might be similar to that of the metal-rich globular clusters. The existence of large numbers of RR Lyrae stars in the galactic nucleus shows that it contains population II stars. It does not however follow that Population II stars constitute the dominant population of the nucleus.

The discussions during the study week clearly revealed that we do not yet understand the sequence of events which leads to the existence within our galaxy of stars with such a wide range of compositions and kinematical characteristics.

In a paper on stars with known parallaxes, Sandage draws attention to the existence of a number of subgiant stars which lie below the giant branch of M 67. This indicates that metal-rich stars exist in the galaxy with ages larger than 5×10^9 years.

Finally attention should be drawn to an interesting paper by Strömgren on the use of narrow band filters for determining stellar characteristics. This method holds great promise for the future.

The proceedings of the Vatican Conference clearly show the value of a meeting of a small number of experts. The inclusion of the (often quite lively) discussions after each conference paper has greatly enhanced the value of the volume. Father O'Connell is to be congratulated on the care with which he has edited the conference proceedings.

SIDNEY VAN DEN BERGH

The Green Flash and Other Low Sun Phenomena by D. J. K. O'Connell, S.J. Pages 192; 6½ × 9½ in. Interscience Publishers Inc., New York. Price $6.00.

At sunrise or sunset on days when the atmosphere is very clear and the sun is rising or setting over a sharp horizon one may sometimes see the Green Flash, the last sunlight at sunset or the first sunlight at sunrise showing an intense green colour. The phenomenon lasts only for a few seconds. Few people have seen the Green Flash and they are doubly fortunate; not only have they witnessed a rare and beautiful natural phenomenon but also, according to legend, they will henceforth prove skillful in affairs of the heart.

Father O'Connell set himself the task of observing the Green Flash and related phenomena from the Vatican Observatory and his work is reported in this book. It contains a very extensive record of observations together with relevant meteorological data. A unique feature of this work are the eighty colour photographs obtained by C. Treusch, S.J. with the astronomical telescopes of the Vatican Observatory in combination with a Leica camera.

Apart from its obvious value as a scientific study of this rare occurrence this book will be an inspiration to amateur astronomers in showing how colour photography with a telescope can be applied to the study of fascinating and often ill-understood meteorological phenomena. In this connection it may be remarked that Father O'Connell expresses his admiration for Professor Minnaert's book, *Light and Colour in the Open Air*, (Dover Publications), a book that deserves to be more widely known among amateurs. In his preface to that book Minnaert writes, "It is indeed wrong to think that the poetry of Nature's moods in all their infinite variety is lost on one who observes them scientifically." Father O'Connell's interesting and delightful monograph illustrates the truth of this remark.

LEONARD SEARLE

BRIEF NOTICES

Manual for Observing Variable Stars by Margaret W. Mayall. Pages 38; 5¼ × 8½ in. American Association of Variable Star Observers, 1957. Price $1.00.

A new, revised edition of the American Association of Variable Star Observers' instructions. Fundamental for all amateur variable star observers.

Planetary Co-ordinates for the Years 1960–1980, referred to the Equinox of 1950.0, prepared by H. M. Nautical Almanac Office. Pages xix plus 160, 8½ × 11¼ in. London, Her Majesty's Stationery Office, 1958. Price £1 10*s*. 0*d*.

This volume is a continuation of two previous volumes published in 1933 and 1939, and extends to 1980 the basic planetary data required in the computation of planetary perturbations. The tables are designed for use by a computer with a desk calculating machine.

Along with the quantities tabulated for each of the planets is given a comparison of eight methods of calculating the perturbations of a comet or minor planet; all the necessary formulae are included as well as numerical examples.

1001 Questions Answered About Astronomy by James S. Pickering. Pp. xi 420; 5¾ × 8½ in. New York, Dodd, Mead & Company, 1958. Price $6.75.

Over a thousand (1043) questions concerning the universe are asked and answered by a member of the staff of the Hayden Planetarium. The division of the book into seventeen sections and a fine index allows reference to a particular topic. Good for browsing.

Space Exploration by Patrick Moore. Pages 36; 4¾ × 7¼ in. (paper). Cambridge, National Book League by University Press, 1958. (The Macmillan Company of Canada Limited.) Price 60¢.

A classified reading list of roughly 120 books for those who want a background for the present-day space research.

Der Sternehimmel, 1959, edited by Robert A. Naef. Pages 126, 6 × 8¼ in. Aarau, H. R. Sauerlauder and Co. (Obtainable through Albert J. Pheibig, P.O. Box 352, White Plains, N.Y.)

The astronomical yearbook sponsored by the Swiss Astronomical Society, well illustrated with diagrams.

Vol 53, No. 1 FEBRUARY 1959 Whole No. 436

Variable Star Observing in New Zealand (concluded) ..... *Frank M. Bateson* 1

The Characteristics of Subdwarf Stars ..... *William Buscombe* 7

The Meanook-Newbrook Meteor Observatories ..... *Peter M. Millman* 15

CANADIAN SCIENTISTS REPORT—XIV
Geological Time ..... *R. M. Faquhar* 34

VARIABLE STAR NOTES ..... *Margaret W. Mayall* 43

NOTES FROM OBSERVATORIES 43

NOTES 44

REVIEW OF PUBLICATIONS

Stellar Populations edited by D. J. K. O'Connell, S.J.; *The Green Flash and Other Low Sun Phenomena* by D. J. K. O'Connell, S.J.; *Manual for Observing Variable Stars* by Margaret W. Mayall; *Planetary Co-ordinates for the Years 1960–1980, referred to the Equinox of 1950.0* prepared by H. M. Nautical Almanac Office; *1001 Questions Answered About Astronomy* by James S. Pickering; *Space Exploration* by Patrick Moore; *Der Sternenhimmel*, 1959 edited by Robert A. Naef 45

EDITOR—Ruth J. Northcott ASSISTANT EDITOR—Leonard Searle

ASSOCIATE EDITORS—C. S. Beals, R. M. Petrie, A. Thomson

COMMUNICATIONS TO THE EDITORS SHOULD BE ADDRESSED TO

David Dunlap Observatory, Richmond Hill, Ontario

The Society publishes this JOURNAL bi-monthly (February, April, June, August, October and December) and the OBSERVER'S HANDBOOK annually. Single copies of either of these publications are 75 cents.

Membership, which includes the publications, is open to anyone interested in astronomy. Annual dues are $5.00; life membership is $75.00. Application for membership or publications should be made to THE ROYAL ASTRONOMICAL SOCIETY OF CANADA, 252 COLLEGE STREET, TORONTO 2B, ONTARIO.